

ACR Appropriateness Criteria[®] Suspected Physical Abuse—Child

Expert Panel on Pediatric Imaging: *Sandra L. Wootton-Gorges, MD^a, Bruno P. Soares, MD^b, Adina L. Alazraki, MD^c, Sudha A. Anupindi, MD^d, Jeffrey P. Blount, MD^e, Timothy N. Booth, MD^{f,g}, Molly E. Dempsey, MD^b, Richard A. Falcone Jr, MD, MPHⁱ, Laura L. Hayes, MD^c, Abhaya V. Kulkarni, MD^j, Sonia Partap, MD^k, Cynthia K. Rigsby, MD^l, Maura E. Ryan, MD^l, Nabile M. Safdar, MD, MPH^m, Andrew T. Trout, MDⁿ, Roger F. Widmann, MD^o, Boaz K. Karmazyn, MD^p, Susan Palasis, MD^q*

Abstract

The youngest children, particularly in the first year of life, are the most vulnerable to physical abuse. Skeletal survey is the universal screening examination in children 24 months of age and younger. Fractures occur in over half of abused children. Rib fractures may be the only abnormality in about 30%. A repeat limited skeletal survey after 2 weeks can detect additional fractures and can provide fracture dating information. The type and extent of additional imaging for pediatric patients being evaluated for suspected physical abuse depends on the age of the child, the presence of neurologic signs and symptoms, evidence of thoracic or abdominopelvic injuries, and social considerations. Unenhanced CT of the head is the initial study for suspected intracranial injury. Clinically occult abusive head trauma can occur, especially in young infants. Therefore, head CT should be performed in selected neurologically asymptomatic physical abuse patients. Contrast-enhanced CT of the abdomen/pelvis is utilized for suspected intra-abdominal or pelvic injury. Particular attention should be paid to discrepancies between the patterns of injury and the reported clinical history. Making the diagnosis of child abuse also requires differentiation from anatomical and developmental variants and possible underlying metabolic and genetic conditions.

The American College of Radiology Appropriateness Criteria are evidence-based guidelines for specific clinical conditions that are reviewed annually by a multidisciplinary expert panel. The guideline development and revision include an extensive analysis of current medical literature from peer-reviewed journals and the application of well-established methodologies (RAND/UCLA Appropriateness Method and Grading of Recommendations Assessment, Development, and Evaluation or GRADE) to rate the appropriateness of imaging and treatment procedures for specific clinical scenarios. In those instances where evidence is lacking or equivocal, expert opinion may supplement the available evidence to recommend imaging or treatment.

Key Words: Appropriateness Criteria, Appropriate Use Criteria, AUC, child abuse, CT, MRI, nonaccidental trauma, pediatric, shaken baby, skeletal survey

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^aPrincipal Author, University of California Davis Medical Center, Sacramento, California.

^bCo-author, Johns Hopkins University School of Medicine, Baltimore, Maryland.

^cChildren's Healthcare of Atlanta, Atlanta, Georgia.

^dChildren's Hospital of Philadelphia, Philadelphia, Pennsylvania.

^eChildren's of Alabama, Birmingham, Alabama, neurosurgical consultant.

^fChildren's Health, Dallas, Texas.

^gUniversity of Texas Southwestern Medical Center, Dallas, Texas.

^hTexas Scottish Rite Hospital for Children, Dallas, Texas.

ⁱCincinnati Children's Hospital Medical Center, Cincinnati, Ohio; American Pediatric Surgical Association.

^jHospital for Sick Children, Toronto, Ontario, Canada, neurosurgical consultant.

^kStanford University, Stanford, California.

^lAnn & Robert H. Lurie Children's Hospital of Chicago, Chicago, Illinois.

^mEmory University, Atlanta, Georgia.

ⁿCincinnati Children's Hospital Medical Center, Cincinnati, Ohio.

^oHospital for Special Surgery, New York, New York; American Academy of Orthopaedic Surgeons.

^pSpecialty Chair, Riley Hospital for Children, Indiana University, Indianapolis, Indiana.

^qPanel Chair, Emory University and Children's Healthcare of Atlanta, Atlanta, Georgia.

Corresponding author: Bruno P. Soares, MD, Attn: Pediatric Radiology, Zayed, Rm 4174 1800 Orleans St, Baltimore, MD 21287; e-mail: bruno.soares@jhmi.edu.

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Disclaimer: The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists, and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.

ACR Appropriateness Criteria[®] Suspected Physical Abuse—Child. Variants 1 to 5 and Table 1.

Variant 1. Suspected physical abuse. Child ≤ 24 months of age. Neurologic or visceral injuries not clinically suspected. Initial imaging evaluation.

Radiologic Procedure	Rating	Comments	RRL
X-ray skeletal survey	9		☼☼☼
MRI head without IV contrast	6		○
CT head without IV contrast	5		☼☼☼
Tc-99m bone scan whole body	4	This procedure is used as a problem-solving study rather than first-line.	☼☼☼☼
MRI head without and with IV contrast	2		○
CT head with IV contrast	1		☼☼☼
CT head without and with IV contrast	1		☼☼☼☼

Note: Rating scale: 1, 2, 3 = usually not appropriate; 4, 5, 6 = may be appropriate; 7, 8, 9 = usually appropriate. IV = intravenous; RRL = relative radiation level.

Variant 2. Suspected physical abuse. Child > 24 months of age. Neurologic or visceral injuries not clinically suspected. Initial imaging evaluation.

Radiologic Procedure	Rating	Comments	RRL
X-ray area of interest	9		Varies
CT head without IV contrast	6		☼☼☼
X-ray skeletal survey	5	Consider this procedure in children unable to verbalize location(s) of pain.	☼☼☼
MRI head without IV contrast	5		○
Tc-99m bone scan whole body	4	This procedure is used as a problem-solving study rather than first-line.	☼☼☼☼
MRI head without and with IV contrast	2		○
CT head with IV contrast	1		☼☼☼
CT head without and with IV contrast	1		☼☼☼☼

Note: Rating scale: 1, 2, 3 = usually not appropriate; 4, 5, 6 = may be appropriate; 7, 8, 9 = usually appropriate. IV = intravenous; RRL = relative radiation level.

Variant 3. Child with one or more of the following: neurologic signs or symptoms, apnea, complex skull fracture, other fractures, or injuries highly suspicious for child abuse. Initial imaging evaluation.

Radiologic Procedure	Rating	Comments	RRL
X-ray skeletal survey	9		☼☼☼
CT head without IV contrast	9	Use this procedure in the emergent setting.	☼☼☼
MRI head without IV contrast	8	This procedure typically performed in the nonemergent setting.	○
MRI cervical spine without IV contrast	8	Consider this procedure at the time of MRI brain imaging.	○
MRI complete spine without IV contrast	5		○
Tc-99m bone scan whole body	5	This procedure is used as a problem-solving study rather than first-line.	☼☼☼☼
MRI head without and with IV contrast	3		○
MRI cervical spine without and with IV contrast	2		○
MRI complete spine without and with IV contrast	2		○
CT head with IV contrast	1		☼☼☼
CT head without and with IV contrast	1		☼☼☼☼

Note: Rating scale: 1, 2, 3 = usually not appropriate; 4, 5, 6 = may be appropriate; 7, 8, 9 = usually appropriate. IV = intravenous; RRL = relative radiation level.

Variant 4. Child. Suspected physical abuse. Suspected thoracic or abdominopelvic injuries (eg, abdominal skin bruises, distension, tenderness, or elevated liver or pancreatic enzymes). Initial imaging evaluation.

Radiologic Procedure	Rating	Comments	RRL
X-ray skeletal survey	9		⊕⊕⊕
CT abdomen and pelvis with IV contrast	9		⊕⊕⊕⊕
CT chest with IV contrast	6	This procedure may be combined with CT abdomen/pelvis with IV contrast if there is concern for intrathoracic injury.	⊕⊕⊕⊕
CT head without IV contrast	6	Use this procedure in the emergent setting if there is suspicion for concurrent intracranial injury.	⊕⊕⊕
MRI head without IV contrast	6	This procedure typically performed in the nonemergent setting.	○
Tc-99m bone scan whole body	4		⊕⊕⊕⊕
CT chest without IV contrast	3	This procedure may be useful in limited situations, such as rib fracture evaluation.	⊕⊕⊕⊕
MRI head without and with IV contrast	2		○
CT abdomen and pelvis without IV contrast	2		⊕⊕⊕⊕
CT abdomen and pelvis without and with IV contrast	1		⊕⊕⊕⊕⊕
CT head with IV contrast	1		⊕⊕⊕
CT head without and with IV contrast	1		⊕⊕⊕⊕

Note: Rating scale: 1, 2, 3 = usually not appropriate; 4, 5, 6 = may be appropriate; 7, 8, 9 = usually appropriate. IV = intravenous; RRL = relative radiation level.

Variant 5. Child ≤ 24 months of age. High suspicion for abuse. Negative initial skeletal survey. Follow-up imaging evaluation.

Radiologic Procedure	Rating	Comments	RRL
X-ray skeletal survey	9	This procedure is a limited (or focused) survey for follow-up after 2 wk.	⊕⊕⊕
Tc-99m bone scan whole body	6	This procedure is used as a problem-solving study rather than first-line.	⊕⊕⊕⊕
CT chest without IV contrast	5		⊕⊕⊕⊕
MRI head without IV contrast	5	Neurologic examination may be difficult in this age group.	○
CT head without IV contrast	4		⊕⊕⊕
MRI head without and with IV contrast	2		○
CT head with IV contrast	1		⊕⊕⊕
CT head without and with IV contrast	1		⊕⊕⊕⊕
CT chest with IV contrast	1		⊕⊕⊕⊕
CT chest without and with IV contrast	1		⊕⊕⊕⊕

Note: Rating scale: 1, 2, 3 = usually not appropriate; 4, 5, 6 = may be appropriate; 7, 8, 9 = usually appropriate. IV = intravenous; RRL = relative radiation level.

Table 1. Relative radiation level designations

RRL*	Adult Effective Dose Estimate Range (mSv)	Pediatric Effective Dose Estimate Range (mSv)
○	0	0
⊕	<0.1	<0.03
⊕⊕	0.1-1	0.03-0.3
⊕⊕⊕	1-10	0.3-3
⊕⊕⊕⊕	10-30	3-10
⊕⊕⊕⊕⊕	30-100	10-30

*Relative radiation level (RRL) assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The relative radiation levels for these examinations are designated as “varies.”

SUMMARY OF LITERATURE REVIEW

Introduction/Background

Based on reports to child and protective service agencies, an estimated 3.2 million children were investigated for maltreatment (neglect, emotional abuse, sexual abuse, and physical abuse) in the United States in 2013, and an estimated 679,000 (9.1 per 1,000 children) were victims of abuse [1]. The youngest children are most vulnerable; children in their first year of life had the highest rate of victimization at 23.1 per 1,000. An estimated 1,520 children died from abuse, with three-fourths of these under 3 years of age. However, the full extent of child abuse is not known because of underreporting [2,3].

Eighteen percent of maltreated children were physically abused by being hit, shaken, thrown, poisoned, burned, scalded, drowned, and/or suffocated [4]. Physically abused children may present with neurologic injuries, hollow viscus and solid organ injuries, superficial and deep soft tissue injuries, thermal injuries, or fractures [4]. Fractures highly suggestive of physical abuse include rib fractures, classic metaphyseal lesions, those unsuspected or inconsistent with the history or age of the child, multiple fractures involving more than one skeletal area, and fractures of differing ages [5-7]. In some children, physical examination and history may clearly indicate that physical abuse has occurred. In other children, however, the diagnosis of abuse is not so straightforward and requires clinical, laboratory, imaging, pathologic, and forensic evaluation and usually relies on the findings of a multidisciplinary team that includes physicians, social workers, and legal authorities. Imaging often plays a major role in the detection and documentation of physical injury. The type and extent of imaging performed in a child who is a suspected victim of abuse depends on the child's age, signs, symptoms, and other social considerations, such as being the twin or sibling of a physically abused infant [8,9]. Making the diagnosis of child abuse requires differentiation from anatomical and developmental variants [10] and possible underlying metabolic [7] and genetic conditions.

Overview of Imaging Modalities

X-ray skeletal survey. The radiographic skeletal survey is the primary imaging examination for detecting fractures [11]. The skeletal survey should be composed of frontal and lateral views of the skull, lateral views of the

cervical spine and thoracolumbosacral spine, and single frontal views of the long bones, hands, feet, chest, and abdomen. Oblique views of the ribs should be obtained to increase the accuracy of diagnosing rib fractures [12,13], which are strong positive predictors and may be the only skeletal manifestation of abuse [14,15].

The images should be obtained using high-detail imaging systems and coned to the specific area of interest for each of the body parts, with separate views of each arm, forearm, thigh, leg, hand, and foot to improve image quality and diagnostic accuracy [16] (see Appendix 1). Fractures most often involve the long bones and ribs, with lesser involvement of the skull and clavicles and even less frequent involvement of the pelvis, spine, hands, and feet [17]. It has therefore been questioned whether the radiation exposure outweighs the potential benefit of imaging the pelvis, spine, hands, and feet on initial skeletal survey [17-20]. Although not part of ACR or American Academy of Pediatrics guidelines, some add lateral radiographs of the long bones, which have been shown to increase detection of metaphyseal fractures by 50% [21]. A repeat skeletal survey performed approximately 2 weeks after the initial examination can provide additional information on the presence and age of child abuse fractures [22] in up to 12% of children and should be performed when abnormal or equivocal findings are found on the initial study and when abuse is suspected on clinical grounds [23]. To limit radiation exposure, pelvis, spine, and skull radiographs can be omitted if no injury was initially seen in these regions [24-26]. However, it is not possible to exactly date fractures by radiography [27].

Tc-99m bone scan whole body. In experienced hands, bone scintigraphy is a complementary or adjunctive examination for detecting bone injuries [28,29] but is usually not considered an alternative to skeletal survey. It should be used when the radiographic skeletal survey is negative but clinical suspicion remains high and a search for further evidence of skeletal trauma is warranted. It may aid by detecting bony injury that is occult, equivocal, or subtle on plain radiographs, but it requires venipuncture and often requires sedation. In addition to standard images, the use of pinhole collimators [29] and differential counts of the metaphyses may improve sensitivity. A bone scan is especially good for detecting periosteal reaction and rib, spine, pelvic, and acromion fractures [23,30]. However, skull fractures and fractures near the growth plates, because of normally increased activity in the growth

plate, may be difficult to appreciate [31,32]. Bone scan is also not useful in dating of fractures, as the scan may be active for up to a year after injury [29].

CT head without contrast. Unenhanced CT of the head is the examination of choice to evaluate children with suspected abusive head trauma (AHT) [33]. These include children who had skeletal survey for suspected child abuse, children with neurologic changes, and children with facial injuries raising concern for abuse. Multiplanar reformations and 3-D volume rendering of the skull increase sensitivity for fracture and intracranial hemorrhage [34,35].

MRI head without contrast. MRI is sensitive for the detection of small-volume extra-axial hemorrhage and for evolving parenchymal injury [36]. In addition to standard sequences, diffusion-weighted imaging and susceptibility-weighted imaging increase sensitivity for detection of parenchymal ischemia, diffuse axonal injury, and microhemorrhage and can provide prognostic information in AHT. The addition of contrast-enhanced MRI sequences can be used in select cases to improve evaluation of extra-axial collections [37] because it increases the sensitivity for the detection of membranes in subdural collections, a finding that indicates a chronic component [37]. Care must be taken when attempting to date subdural collections, however, because the imaging appearance depends not just on the age of blood products but also on the potential presence of cerebrospinal fluid accumulation in the subdural space through an arachnoid laceration (hematoxygroma) [38]. Thrombosis of bridging veins in the subdural space also suggests abusive trauma [39,40].

The MRI should include T1- and T2-weighted imaging as well as T2 fluid attenuation inversion recovery and T2* (gradient-echo or susceptibility-weighted imaging) sequences. Diffusion-weighted sequences are required to indicate whether acute cerebral injury is present [36]. Susceptibility-weighted imaging may be useful in detection of blood products in the brain as well as retinal hemorrhages [41,42]. MRI is a particularly good choice to image children at high risk for AHT in the nonemergent setting but is a lengthy scan often requiring sedation, so it is typically not utilized in the emergent setting.

MRI spine. Recent evidence supports that spine injury is common in children with AHT. In recent retrospective studies [43-45], ligamentous injury at the craniocervical junction and spinal subdural

hemorrhage (SDH) are reported in 36% to 78% and 44% to 63% of AHT cases, respectively. MRI of the cervical spine, including fat-suppressed fluid-sensitive sequences, a sagittal short tau inversion recovery, or T2 fat-saturated sequence, should be performed in all cases where the skeletal survey demonstrates any fractures or when clinical concern for craniocervical junction or spinal injury is high. The prevalence of spine fracture is increased to almost 10% in the setting of a positive skeletal survey and is significantly associated with intracranial injury [18]. The high incidence of cervical injuries in abused children with bilateral hypoxic-ischemic brain injuries suggests a causal relationship [44].

The value of routine screening of the whole spine in suspected AHT is still debated. In a subgroup of 38 children with AHT who underwent thoracolumbar spine imaging, 24 (63%) had thoracolumbar SDH, whereas only 1 of 70 patients with accidental trauma had spinal SDH in the same study [43]. None of the children had spinal cord compression or long-term complications from the presence of the spinal SDH, and that imaging was performed mostly because of concern for thoracic or abdominal injury. Although not usually prompting change in management, detection of spinal SDH is significantly increased when imaging is extended through the thoracolumbar spine [45]. The presence of thoracolumbar SDH does not imply direct trauma to the thoracolumbar spine and may be related to redistribution of blood products. Nevertheless, this finding has medicolegal implications as it may document otherwise undetected injury and may help distinguish between abusive and accidental injury.

CT chest without contrast. CT of the chest is more sensitive than chest radiography in detection of rib fractures; chest radiography defines only about 60% of the fractures that are detected by CT [46]. Anterior and posterior fractures are better seen by CT, as are bilateral fractures. However, the need for sedation in noncooperative children makes this test a useful adjunct rather than a first-line test in the imaging workup of nonaccidental trauma (NAT). A reduced-dose chest CT may detect rib fractures in infants with high suspicion for NAT and a normal initial four-view chest, with a submillisievert radiation dose equaling twice that of a four-view chest [47]. Multiplanar reformatted images may aid in rib fracture detection [48]. In addition, chest CT may detect scapular and spine fractures not evident on skeletal survey [47].

CT chest with contrast. A CT scan of the chest with intravenous contrast is reserved for children with clinical suspicion of intrathoracic traumatic injury. Intravenous contrast allows for detection of vascular injuries.

CT abdomen and pelvis with contrast. CT of the abdomen and pelvis with intravenous contrast is utilized for children with suspected intra-abdominal and/or intrapelvic injury [49]. Portal venous phase imaging is most helpful for detecting solid organ injury. Delayed excretory-phase imaging may be useful in a few selected cases when imaging findings suggest disruption of the genitourinary tract. Noncontrast abdominal CT is not recommended. The need for oral contrast is at the discretion of the radiologist, and its use may be considered when there is concern for duodenal hematoma [23].

DISCUSSION OF IMAGING MODALITIES BY VARIANT

Variant 1: Suspected physical abuse. Child \leq 24 months of age. Neurologic or visceral injuries not clinically suspected. Initial imaging evaluation

X-ray skeletal survey. Children $<$ 6 months of age with bruising raising the possibility of NAT have a high incidence of additional injuries [50]. Radiographic skeletal surveys are the initial imaging modality of choice because fractures occur in up to 55% of physically abused children [29]. The majority of skeletal surveys that are positive for fractures are performed in children $<$ 1 year of age, and 80% of abused children with fractures are $<$ 18 months of age [4]. Thus, skeletal survey is recommended in all children $<$ 2 years of age in whom there is suspicion of abuse [51,52]. Of infants undergoing evaluation for abuse, 11% to 20% have an unsuspected fracture detected by skeletal survey [53,54]. Fractures that are highly specific for NAT in the normal child include those involving the posterior ribs [14], classic metaphyseal lesions [55] or epiphyseal separation injuries, and avulsive fractures of the acromion process [6]. Rib fractures may be the only skeletal abnormality in about 30% of physically abused infants [14].

Highly suggestive skeletal injuries include fractures that are unsuspected or inconsistent with the provided history or age of the child, multiple fractures involving more than one skeletal area, fractures of differing ages, and a combination of skeletal and nonskeletal injuries [5,6]. In addition, fractures of the radius, ulna, tibia, fibula, or femur that occur in children $<$ 1 year of age and midshaft or metaphyseal humeral fractures should

be considered suspicious for abuse [56,57]. The child's motor developmental level is a key discriminator for abuse in certain fractures. In particular, femoral fractures in a child who is not yet walking and unexplained humeral fractures in children $<$ 15 months of age should be considered suspicious for abuse [56]. Multiple fractures in any location without overt trauma are strongly associated with abusive injury [4]. Pediatric contacts of abused children may also need to be screened by skeletal survey, especially twins [9].

Tc-99m bone scan whole body. Bone scintigraphy is a complementary/adjunctive examination for detecting bone injuries [28,29] but is usually not considered an alternative to skeletal survey. It should be used when the radiographic skeletal survey is negative but clinical suspicion remains high and search for further evidence of skeletal trauma is warranted. It may aid by detecting bony injury that is occult, equivocal, or subtle on plain radiographs, but it requires venipuncture and often requires sedation.

CT head and MRI head. There are varying opinions on how to image suspected abuse victims who show no evidence suggesting intracranial injury. Although skull radiographs may detect fractures associated with intracranial pathology, they do not provide adequate screening, because significant traumatic intracranial pathology may occur in the absence of skull fractures [58,59]. Children, especially those $<$ 12 months of age, may have significant intracranial injury without signs or symptoms of head injury or retinal hemorrhage [60-62]. Unenhanced CT of the head is the examination of choice for initial evaluation for intracranial injury in child abuse [33]. MRI is a good choice to image children for abusive head injury in the nonemergent setting.

A study of abused children without clinical suspicion of intracranial injury showed that 11 (29%) of the 51 children had positive neuroimaging including subdural hematoma, epidural hematoma, or cerebral edema; most of them had negative skeletal surveys and no retinal hemorrhage. Of the 11 children, 8 were $<$ 12 months of age [60]. In another prospective study of infants $<$ 6 months of age evaluated for possible physical abuse, the presence of apparently isolated bruises (seen in 146 children) at presentation correlated with new injury on neuroimaging in 40 children (27%) [50]. In yet another study [61], 37% of children $<$ 2 years of age with high-risk criteria (defined as rib fractures, multiple fractures, facial injury, or $<$ 6 months of age) and without overt signs of head injury who underwent head CT or

MRI had occult head injury; nearly all with occult head injury were <1 year of age. Intracranial injury is also associated with spinal trauma seen on skeletal survey [18]. Given these studies, clinicians should have a relatively low threshold for performing either CT (emergent setting and more sensitive for detection of nondisplaced fractures) or MRI of the head in children with suspected abuse.

In summary, there is no strong evidence to recommend universal screening with neuroimaging. However, clinicians should have low threshold for performing head CT or MRI in young children with suspected child abuse.

Variant 2: Suspected physical abuse. Child > 24 months of age. Neurologic or visceral injuries not clinically suspected. Initial imaging evaluation

X-ray area of interest. Children > 2 years of age are often able to verbalize the area(s) of injury or pain during clinical examination. Thus, initial imaging should focus on the areas of clinical concern.

X-ray skeletal survey. In children > 2 years of age, skeletal survey is usually not done but may be performed based on clinical findings and the need to document the presence or absence of injuries. In this older group of children, skeletal imaging should be strongly considered in a child who has unexplained craniocerebral or abdominal injuries or fractures that are suspicious for abuse. Multiple areas of fracture and unusual fractures should raise one's suspicion for child abuse; the common accidental fractures in children of this age group are distal humeral and distal radius or ulna after a short fall [63].

Tc-99m bone scan whole body. Bone scintigraphy is a complementary or adjunctive examination for detecting bone injuries. It may aid by detecting bony injury that is occult, equivocal, or subtle on plain radiographs, but the study requires venipuncture and often requires sedation.

CT head and MRI head. Unenhanced CT of the head is the examination of choice for acute evaluation for intracranial injury in child abuse [33]. However, there is no strong evidence to recommend universal screening with neuroimaging in the absence of clinical suspicion for AHT. This is particularly true in older children where the neurologic examination is typically more reliable, except for children with chronic disabilities.

MRI is a good choice to image children for abusive head injury in the nonemergent setting. MRI is useful in the detection of small-volume extra-axial hemorrhage and

for evolving parenchymal injury [36]. Diffusion-weighted imaging and susceptibility-weighted imaging increase the sensitivity for detection of parenchymal ischemia, diffuse axonal injury, and microhemorrhage. The addition of contrast-enhanced MRI sequences can be utilized in select cases to improve evaluation of extra-axial fluid collections.

Variant 3: Child with one or more of the following: neurologic signs or symptoms, apnea, complex skull fracture, other fractures, or injuries highly suspicious for child abuse. Initial imaging evaluation

X-ray skeletal survey. The skeletal survey is the primary examination for detecting fractures [11]. Fractures occur in up to 55% of physically abused children [29]; 80% of abused children with fractures are <18 months of age [4]. Thus, skeletal survey is recommended in all children < 2 years of age in whom there is suspicion of abuse [51,52].

Tc-99m bone scan whole body. Bone scintigraphy is a complementary/adjunctive examination for detecting bone injuries. It may aid by detecting bony injury that is occult, equivocal, or subtle on plain radiographs. Skull fractures and fractures near the growth plates, however, may be difficult to appreciate [31,32].

CT head. Although less frequent than skeletal injuries, most child abuse fatalities are the result of head trauma [64], and head injury due to child abuse is the principal cause of death in children < 2 years of age [61]. AHT is responsible for the majority of severe traumatic brain injury in children < 2 years of age, with case fatality rates above 20% [65]. Subdural hematoma is the most commonly seen intracranial abnormality (multiple, convexity, interhemispheric, posterior fossa) [66]. Additional craniocerebral injuries include cerebral contusion, epidural hematoma, cerebral edema, subarachnoid hemorrhage, and unilateral hypoxic or ischemic injury. Imaging the head in children with suspected abuse depends on the child's age and type of presentation.

In children with skull fractures or clinical signs and symptoms of intracranial injury, an immediate non-contrast CT scan of the head should be performed. Contrast administration for the head CT examination is not indicated. If the CT scan does not detect significant lesions that require rapid neurosurgical intervention and the clinical presentation warrants further assessment, an MRI scan of the head should be performed.

MRI head. Additional diagnostic information will be found on MRI over CT in about 25% of patients [36], and MRI can also contribute to prognosis. In a child with an abnormal CT, additional assessment with MRI should be considered to further assess the extent of post-traumatic injury. Care should be taken in trying to determine the age of subdural hematomas by CT or MRI [67,68]. Although hyperdense blood products can be considered acute, collections of low or intermediate density do not indicate necessarily chronic blood products, as lacerations of the arachnoid may result in subdural hygromas or hematoxygromas in the early or late post-traumatic periods. MR venography utilizing unenhanced 2-D time-of-flight technique can be used to assess patency of the dural venous sinuses and deep venous system.

Neuroimaging should not be performed as a screening examination in all children but should be used for further evaluation of all abnormal initial examinations and in cases of clinical suspicion [36]. The clinician should have a relatively low threshold for performing either CT (emergent setting) or MRI of the head (nonemergent setting), especially in children under 1 year of age [60,61].

MRI cervical spine. MRI of the cervical spine should be strongly considered at the time of MRI brain imaging, because unsuspected spinal injuries may be demonstrated in >36% of cases [44]. Cervical spine injury, particularly at the craniocervical junction, is highly associated with bilateral hypoxic-ischemic injury. Most cervical spine injury detected by MRI in abused infants is ligamentous.

MRI complete spine. MRI of the entire spine may show thoracolumbar SDH, most commonly from redistribution of blood products; however, it rarely results in cord compression or alters clinical management. An MRI of the total spine should be reserved for cases where the distinction between abusive and accidental trauma is not clear, because thoracolumbar SDH is more commonly seen with abusive trauma [43].

Variant 4: Child. Suspected physical abuse. Suspected thoracic or abdominopelvic injuries (eg, abdominal skin bruises, distension, tenderness, or elevated liver or pancreatic enzymes). Initial imaging evaluation

X-ray skeletal survey. Because most children with thoracic or abdominopelvic injury from child abuse have polytrauma [69], skeletal survey is recommended in all

children 24 months of age or younger and should be considered in older children.

Tc-99m bone scan whole body. Bone scintigraphy is a complementary or adjunctive examination for detecting bone injuries. It may aid by detecting bony injury that is occult, equivocal, or subtle on plain radiographs.

CT head and MRI head. CT or MRI of the head should also be performed in children with neurologic symptoms or risk factors for intracranial injuries (see [variant 3](#)).

CT of the abdomen and pelvis. Nonskeletal injuries to the chest, abdomen, and pelvis can occur as the result of child abuse. Child abuse should be considered in any child with thoracoabdominal injuries that are not consistent with the provided history.

Up to 10% of abused children have intra-abdominal injury [49]; 15% of children aged 0 to 4 years hospitalized for abdominal injury are victims of child abuse [70,71]. Victims of nonaccidental abdominal trauma tend to be younger and have a more delayed presentation than those who experience accidental trauma [72]. Clinical findings of abdominal pain, abdominal distension, vomiting, abdominal wall bruising, and hypoactive or absent bowel sounds may suggest intra-abdominal injury [73-75]. Abnormal liver transaminases and pancreatic enzymes may be seen with occult abdominal trauma [74,75].

One series suggested that nearly half of abused children with abdominal injury require surgical intervention [76]. In addition, independent of concomitant injury, blunt trauma due to child abuse is associated with a 6-fold increase in odds of death compared with children whose injuries resulted from accidental trauma [70]. Nonskeletal abdominopelvic injuries include pancreatitis, pancreatic pseudocysts, and lacerations and contusions of the liver, adrenal gland, spleen, kidneys, and bowel (especially duodenum) [77,78]. Bowel injuries and pancreatic injuries are seen disproportionately more often in child abuse compared with accidental trauma [49]. Contrast-enhanced CT of the abdomen is indicated in acute evaluation of the child with suspected abdominopelvic injuries. The use of ultrasound in the acute setting is limited, because both focused abdominal scan in trauma and standard abdominopelvic ultrasound are less sensitive than CT in detection of hemoperitoneum and solid organ injuries [79,80]. Noncontrast CT of the abdomen is not adequately sensitive in detection of intrathoracic or intra-abdominal trauma. Routine CT scan screening for abdominal or chest injury is not recommended [72].

CT of the chest. Injuries to the chest (other than the ribs) are uncommon and include hemopericardium, cardiac contusions and lacerations, pleural effusion, and lung contusions [23,64,77,81]. Contrast-enhanced CT of the chest is indicated in acute evaluation of the child with these types of suspected nonskeletal intrathoracic injury; noncontrast CT of the chest is not adequately sensitive. Routine CT scan screening for chest injury is not recommended [72].

Variant 5: Child \leq 24 months of age. High suspicion for abuse. Negative initial skeletal survey. Follow-up imaging evaluation

X-ray skeletal survey. Additional imaging may be useful in children suspected of nonaccidental injury whose initial skeletal survey is negative. A negative initial skeletal survey has a true negative rate of about 90% [82], so with high clinical suspicion, it is very appropriate to perform further imaging such as follow-up skeletal survey, bone scan, or noncontrast low-dose CT of the chest.

In children $<$ 24 months of age, a repeat skeletal survey performed approximately 2 weeks after the initial examination can detect fractures not seen on initial skeletal survey, can clarify equivocal findings, and can provide information on the age of child abuse fractures [22,26,83]. After a negative initial survey, 9% to 12% of infants have healing fractures on follow-up survey [82,84], and up to one-third of follow-up surveys yield new information [84]. Half to three-fourths of these newly detected fractures are rib fractures [26,82,84]; classic metaphyseal lesions are the second most common [83]. As such, many authors have suggested a more limited follow-up skeletal survey, as described previously. However, it is not possible to exactly date fractures by radiography [27].

Tc-99m bone scan whole body. In selected cases, when it is not possible to wait 2 weeks for a follow-up skeletal survey radiograph, a bone scan can be considered. Bone scan is sensitive in detecting radiographically occult fractures. It is particularly useful in detection of fractures of the ribs, scapula, spine, and pelvis [30]. It is not sensitive, however, in the detection of skull fractures [29]. Metaphyseal injury may be difficult to see because of the adjacent normal metabolically active physis. Radiation exposure is higher than a skeletal survey [29]. If used in follow-up, radiographs of areas of abnormal uptake should also be performed.

CT chest. Low-dose noncontrast CT of the chest also offers a time advantage over repeat skeletal survey. It is

useful in the detection of rib, scapula, and thoracic spine fractures not seen on skeletal survey [47]. Anterior and posterior rib fractures are detected more often by CT than by skeletal survey [46]. Fractures may also be dated as acute, subacute, or chronic [46,85]. It would not replace contrast-enhanced chest CT in initial evaluation of nonskeletal thoracic injuries, such as hemopericardium, cardiac contusions and lacerations, pleural effusion, and lung contusions [23,64,77,81].

CT head and MRI head. Follow-up neuroimaging is usually not indicated in the setting of a negative skeletal survey and absence of clinical suspicion of AHT. If there is suspicion for injury after the initial evaluation, neuroimaging should be considered. Noncontrast CT is useful in the evaluation of healing skull fractures, whereas MRI is the method of choice to evaluate the intracranial compartment.

SUMMARY OF RECOMMENDATIONS

- The appropriate imaging of pediatric patients being evaluated for suspected physical abuse depends upon the age of the child, the presence of neurologic signs and symptoms, and evidence of visceral thoracic or abdominopelvic injuries.
- A skeletal survey is indicated in the initial imaging evaluation of a child 24 months of age or younger. In older children, it is usually appropriate to target imaging to the area(s) of suspected injury.
- Skeletal survey and CT head without contrast are indicated in the emergent or initial imaging evaluation of a child with neurologic signs and symptoms, complex skull fracture, apnea, multiple fractures, spine trauma, or facial injury. These examinations are not indicated for general screening.
- MRI head may provide additional diagnostic information to head CT in about 25% of children.
- MRI of the cervical spine should be considered at the time of head MRI, as unsuspected injury (usually ligamentous) may be present in over 33% of children with intracranial injury.
- Skeletal survey and CT chest/abdomen/pelvis with IV contrast are indicated if there are signs or symptoms of intrathoracic or intra-abdominal visceral injury (abdominal pain/distension/bruising, abnormal liver, or pancreatic enzymes, etc).

- In children 24 months of age or younger with equivocal skeletal survey or with a high clinical suspicion for abuse and a negative initial skeletal survey, a repeat limited/focused skeletal survey performed at 2 weeks may add diagnostic information.

SUMMARY OF EVIDENCE

Of the 86 references cited in the ACR Appropriateness Criteria[®] Suspected Physical Abuse—Child document, all of them are categorized as diagnostic references including 3 good-quality studies, and 19 quality studies that may have design limitations. There are 62 references that may not be useful as primary evidence. There are 2 references that are meta-analysis studies.

The 86 references cited in the ACR Appropriateness Criteria[®] Suspected Physical Abuse—Child document were published from 1984 to 2016.

While there are references that report on studies with design limitations, 2 good-quality studies provide good evidence.

RELATIVE RADIATION LEVEL INFORMATION

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, both because of organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared to those specified for adults (see Table 1). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria[®] Radiation Dose Assessment Introduction document [86].

SUPPORTING DOCUMENTS

For additional information on the Appropriateness Criteria methodology and other supporting documents go to www.acr.org/ac.

REFERENCES

1. US Department of Health and Human Services, Administration for Children and Families, Administration on Children, Youth and Families, Children's Bureau. Child maltreatment 2013. 2015. Available at: <http://www.acf.hhs.gov/programs/cb/research-data-technology/statistics-research/child-maltreatment>. Accessed November 1, 2016.
2. Gilbert R, Kemp A, Thoburn J, et al. Recognising and responding to child maltreatment. *Lancet* 2009;373:167-80.
3. Hobbs CJ, Bilo RA. Nonaccidental trauma: clinical aspects and epidemiology of child abuse. *Pediatr Radiol* 2009;39:457-60.
4. Mok JY. Non-accidental injury in children—an update. *Injury* 2008;39:978-95.
5. Dwek JR. The radiographic approach to child abuse. *Clin Orthop Relat Res* 2011;469:776-89.
6. Merten DF, Carpenter BL. Radiologic imaging of inflicted injury in the child abuse syndrome. *Pediatr Clin North Am* 1990;37:815-37.
7. Servaes S, Brown SD, Choudhary AK, et al. The etiology and significance of fractures in infants and young children: a critical multidisciplinary review. *Pediatr Radiol* 2016;46:591-600.
8. Becker JC, Liersch R, Tautz C, Schlueter B, Andler W. Shaken baby syndrome: report on four pairs of twins. *Child Abuse Negl* 1998;22:931-7.
9. Lindberg DM, Shapiro RA, Laskey AL, Pallin DJ, Blood EA, Berger RP. Prevalence of abusive injuries in siblings and household contacts of physically abused children. *Pediatrics* 2012;130:193-201.
10. Quigley AJ, Stafrace S. Skeletal survey normal variants, artefacts and commonly misinterpreted findings not to be confused with non-accidental injury. *Pediatr Radiol* 2014;44:82-93; quiz 79-81.
11. van Rijn RR, Sieswerda-Hoogendoorn T. Educational paper: imaging child abuse: the bare bones. *Eur J Pediatr* 2012;171:215-24.
12. Hansen KK, Prince JS, Nixon GW. Oblique chest views as a routine part of skeletal surveys performed for possible physical abuse—is this practice worthwhile? *Child Abuse Negl* 2008;32:155-9.
13. Marine MB, Corea D, Steenburg SD, et al. Is the new ACR-SPR practice guideline for addition of oblique views of the ribs to the skeletal survey for child abuse justified? *AJR Am J Roentgenol* 2014;202:868-71.
14. Barsness KA, Cha ES, Bensard DD, et al. The positive predictive value of rib fractures as an indicator of nonaccidental trauma in children. *J Trauma* 2003;54:1107-10.
15. Cadzow SP, Armstrong KL. Rib fractures in infants: red alert! The clinical features, investigations and child protection outcomes. *J Paediatr Child Health* 2000;36:322-6.
16. American College of Radiology. ACR-SPR Practice Parameter for Skeletal Surveys in Children. Available at: http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/Skeletal_Surveys.pdf. Accessed November 1, 2016.
17. Karmazyn B, Lewis ME, Jennings SG, Hibbard RA, Hicks RA. The prevalence of uncommon fractures on skeletal surveys performed to evaluate for suspected abuse in 930 children: should practice guidelines change? *AJR Am J Roentgenol* 2011;197:W159-63.
18. Barber I, Perez-Rossello JM, Wilson CR, Silvera MV, Kleinman PK. Prevalence and relevance of pediatric spinal fractures in suspected child abuse. *Pediatr Radiol* 2013;43:1507-15.
19. Jha P, Stein-Wexler R, Coulter K, Seibert A, Li CS, Wootton-Gorges SL. Optimizing bone surveys performed for suspected non-accidental trauma with attention to maximizing diagnostic yield while minimizing radiation exposure: utility of pelvic and lateral radiographs. *Pediatr Radiol* 2013;43:668-72.
20. Kleinman PK, Morris NB, Makris J, Moles RL, Kleinman PL. Yield of radiographic skeletal surveys for detection of hand, foot, and spine fractures in suspected child abuse. *AJR Am J Roentgenol* 2013;200:641-4.
21. Phillips KL, Bastin ST, Davies-Payne D, et al. Radiographic skeletal survey for non-accidental injury: systematic review and development of

- a national New Zealand protocol. *J Med Imaging Radiat Oncol* 2015;59:54-65.
22. Harper NS, Eddleman S, Lindberg DM. The utility of follow-up skeletal surveys in child abuse. *Pediatrics* 2013;131:e672-8.
 23. Section on Radiology; American Academy of Pediatrics. Diagnostic imaging of child abuse. *Pediatrics* 2009;123:1430-5.
 24. Hansen KK, Keeshin BR, Flaherty E, et al. Sensitivity of the limited view follow-up skeletal survey. *Pediatrics* 2014;134:242-8.
 25. Sonik A, Stein-Wexler R, Rogers KK, Coulter KP, Wootton-Gorges SL. Follow-up skeletal surveys for suspected non-accidental trauma: can a more limited survey be performed without compromising diagnostic information? *Child Abuse Negl* 2010;34:804-6.
 26. Zimmerman S, Makoroff K, Care M, Thomas A, Shapiro R. Utility of follow-up skeletal surveys in suspected child physical abuse evaluations. *Child Abuse Negl* 2005;29:1075-83.
 27. Prosser I, Maguire S, Harrison SK, Mann M, Sibert JR, Kemp AM. How old is this fracture? Radiologic dating of fractures in children: a systematic review. *AJR Am J Roentgenol* 2005;184:1282-6.
 28. Bainbridge JK, Huey BM, Harrison SK. Should bone scintigraphy be used as a routine adjunct to skeletal survey in the imaging of non-accidental injury? A 10 year review of reports in a single centre. *Clin Radiol* 2015;70:e83-9.
 29. Kemp AM, Butler A, Morris S, et al. Which radiological investigations should be performed to identify fractures in suspected child abuse? *Clin Radiol* 2006;61:723-36.
 30. Conway JJ, Collins M, Tanz RR, et al. The role of bone scintigraphy in detecting child abuse. *Semin Nucl Med* 1993;23:321-3.
 31. Jaudes PK. Comparison of radiography and radionuclide bone scanning in the detection of child abuse. *Pediatrics* 1984;73:166-8.
 32. Mandelstam SA, Cook D, Fitzgerald M, Ditchfield MR. Complementary use of radiological skeletal survey and bone scintigraphy in detection of bony injuries in suspected child abuse. *Arch Dis Child* 2003;88:387-90; discussion 387-90.
 33. Hedlund GL, Frasier LD. Neuroimaging of abusive head trauma. *Forensic Sci Med Pathol* 2009;5:280-90.
 34. Langford S, Panigrahy A, Narayanan S, et al. Multiplanar reconstructed CT images increased depiction of intracranial hemorrhages in pediatric head trauma. *Neuroradiology* 2015;57:1263-8.
 35. Prabhu SP, Newton AW, Perez-Rossello JM, Kleinman PK. Three-dimensional skull models as a problem-solving tool in suspected child abuse. *Pediatr Radiol* 2013;43:575-81.
 36. Kemp AM, Rajaram S, Mann M, et al. What neuroimaging should be performed in children in whom inflicted brain injury (iBI) is suspected? A systematic review. *Clin Radiol* 2009;64:473-83.
 37. Williams VL, Hogg JP. Magnetic resonance imaging of chronic subdural hematoma. *Neurosurg Clin N Am* 2000;11:491-8.
 38. Vezina G. Assessment of the nature and age of subdural collections in nonaccidental head injury with CT and MRI. *Pediatr Radiol* 2009;39:586-90.
 39. Adamsbaum C, Rambaud C. Abusive head trauma: don't overlook bridging vein thrombosis. *Pediatr Radiol* 2012;42:1298-300.
 40. Choudhary AK, Bradford RA, Dias MS, Thamburaj K, Boal DK. Venous injury in abusive head trauma. *Pediatr Radiol* 2015;45:1803-13.
 41. Beavers AJ, Stagner AM, Allbery SM, Lyden ER, Hejkal TW, Haney SB. MR detection of retinal hemorrhages: correlation with graded ophthalmologic exam. *Pediatr Radiol* 2015;45:1363-71.
 42. Zuccoli G, Panigrahy A, Haldipur A, et al. Susceptibility weighted imaging depicts retinal hemorrhages in abusive head trauma. *Neuroradiology* 2013;55:889-93.
 43. Choudhary AK, Bradford RK, Dias MS, Moore GJ, Boal DK. Spinal subdural hemorrhage in abusive head trauma: a retrospective study. *Radiology* 2012;262:216-23.
 44. Kadom N, Khademian Z, Vezina G, Shalaby-Rana E, Rice A, Hinds T. Usefulness of MRI detection of cervical spine and brain injuries in the evaluation of abusive head trauma. *Pediatr Radiol* 2014;44:839-48.
 45. Koumellis P, McConachie NS, Jaspan T. Spinal subdural haematomas in children with non-accidental head injury. *Arch Dis Child* 2009;94:216-9.
 46. Wootton-Gorges SL, Stein-Wexler R, Walton JW, Rosas AJ, Coulter KP, Rogers KK. Comparison of computed tomography and chest radiography in the detection of rib fractures in abused infants. *Child Abuse Negl* 2008;32:659-63.
 47. Sanchez TR, Lee JS, Coulter KP, Seibert JA, Stein-Wexler R. CT of the chest in suspected child abuse using submillisievert radiation dose. *Pediatr Radiol* 2015;45:1072-6.
 48. Alkadhhi H, Wildermuth S, Marincek B, Boehm T. Accuracy and time efficiency for the detection of thoracic cage fractures: volume rendering compared with transverse computed tomography images. *J Comput Assist Tomogr* 2004;28:378-85.
 49. Sheybani EF, Gonzalez-Araiza G, Kousari YM, Hulett RL, Menias CO. Pediatric nonaccidental abdominal trauma: what the radiologist should know. *Radiographics* 2014;34:139-53.
 50. Harper NS, Feldman KW, Sugar NF, Anderst JD, Lindberg DM. Additional injuries in young infants with concern for abuse and apparently isolated bruises. *J Pediatr* 2014;165:383-8. e381.
 51. Lindberg DM, Berger RP, Reynolds MS, Alwan RM, Harper NS. Yield of skeletal survey by age in children referred to abuse specialists. *J Pediatr* 2014;164:1268-73. e1261.
 52. Wood JN, Fakeye O, Feudtner C, Mondestin V, Localio R, Rubin DM. Development of guidelines for skeletal survey in young children with fractures. *Pediatrics* 2014;134:45-53.
 53. Barber I, Perez-Rossello JM, Wilson CR, Kleinman PK. The yield of high-detail radiographic skeletal surveys in suspected infant abuse. *Pediatr Radiol* 2015;45:69-80.
 54. Duffy SO, Squires J, Fromkin JB, Berger RP. Use of skeletal surveys to evaluate for physical abuse: analysis of 703 consecutive skeletal surveys. *Pediatrics* 2011;127:e47-52.
 55. Kleinman PK, Perez-Rossello JM, Newton AW, Feldman HA, Kleinman PL. Prevalence of the classic metaphyseal lesion in infants at low versus high risk for abuse. *AJR Am J Roentgenol* 2011;197:1005-8.
 56. Leventhal JM, Thomas SA, Rosenfield NS, Markowitz RI. Fractures in young children. Distinguishing child abuse from unintentional injuries. *Am J Dis Child* 1993;147:87-92.
 57. Shrader MW, Bernat NM, Segal LS. Suspected nonaccidental trauma and femoral shaft fractures in children. *Orthopedics* 2011;34:360.
 58. Lloyd DA, Carty H, Patterson M, Butcher CK, Roe D. Predictive value of skull radiography for intracranial injury in children with blunt head injury. *Lancet* 1997;349:821-4.
 59. Quayle KS, Jaffe DM, Kuppermann N, et al. Diagnostic testing for acute head injury in children: when are head computed tomography and skull radiographs indicated? *Pediatrics* 1997;99:E11.
 60. Laskey AL, Holsti M, Runyan DK, Socolar RR. Occult head trauma in young suspected victims of physical abuse. *J Pediatr* 2004;144:719-22.
 61. Rubin DM, Christian CW, Bilaniuk LT, Zazyczny KA, Durbin DR. Occult head injury in high-risk abused children. *Pediatrics* 2003;111(6 Pt 1):1382-6.
 62. Wilson PM, Chua M, Care M, Greiner MV, Keeshin B, Bennett B. Utility of head computed tomography in children with a single extremity fracture. *J Pediatr* 2014;164:1274-9.
 63. Rennie L, Court-Brown CM, Mok JY, Beattie TF. The epidemiology of fractures in children. *Injury* 2007;38:913-22.
 64. Kellogg ND. Evaluation of suspected child physical abuse. *Pediatrics* 2007;119:1232-41.
 65. Keenan HT, Runyan DK, Marshall SW, Nocera MA, Merten DF, Sinal SH. A population-based study of inflicted traumatic brain injury in young children. *JAMA* 2003;290:621-6.
 66. Kemp AM, Jaspan T, Griffiths J, et al. Neuroimaging: what neuro-radiological features distinguish abusive from non-abusive head trauma? A systematic review. *Arch Dis Child* 2011;96:1103-12.

67. Cramer JA, Rassner UA, Hedlund GL. Limitations of T2*-gradient recalled-echo and susceptibility-weighted imaging in characterizing chronic subdural hemorrhage in infant survivors of abusive head trauma. *AJNR Am J Neuroradiol* 2016;39:1752-6.
68. Sieswerda-Hoogendoorn T, Postema FA, Verbaan D, Majoie CB, van Rijn RR. Age determination of subdural hematomas with CT and MRI: a systematic review. *Eur J Radiol* 2014;83:1257-68.
69. Larimer EL, Fallon SC, Westfall J, Frost M, Wesson DE, Naik-Mathuria BJ. The importance of surgeon involvement in the evaluation of non-accidental trauma patients. *J Pediatr Surg* 2013;48:1357-62.
70. Trokel M, DiScala C, Terrin NC, Sege RD. Blunt abdominal injury in the young pediatric patient: child abuse and patient outcomes. *Child Maltreat* 2004;9:111-7.
71. Trokel M, DiScala C, Terrin NC, Sege RD. Patient and injury characteristics in abusive abdominal injuries. *Pediatr Emerg Care* 2006;22:700-4.
72. Ledbetter DJ, Hatch EI Jr, Feldman KW, Fligner CL, Tapper D. Diagnostic and surgical implications of child abuse. *Arch Surg* 1988;123:1101-5.
73. Hilmes MA, Hernanz-Schulman M, Greeley CS, Piercey LM, Yu C, Kan JH. CT identification of abdominal injuries in abused pre-school-age children. *Pediatr Radiol* 2011;41:643-51.
74. Lindberg D, Makoroff K, Harper N, et al. Utility of hepatic transaminases to recognize abuse in children. *Pediatrics* 2009;124:509-16.
75. Trout AT, Strouse PJ, Mohr BA, Khalatbari S, Myles JD. Abdominal and pelvic CT in cases of suspected abuse: can clinical and laboratory findings guide its use? *Pediatr Radiol* 2011;41:92-8.
76. Roaten JB, Partrick DA, Bensard DD, et al. Visceral injuries in non-accidental trauma: spectrum of injury and outcomes. *Am J Surg* 2005;190:827-9.
77. Lonergan GJ, Baker AM, Morey MK, Boos SC. From the archives of the AFIP. Child abuse: radiologic-pathologic correlation. *Radiographics* 2003;23:811-45.
78. Maguire SA, Upadhyaya M, Evans A, et al. A systematic review of abusive visceral injuries in childhood—their range and recognition. *Child Abuse Negl* 2013;37:430-45.
79. Holmes JF, Gladman A, Chang CH. Performance of abdominal ultrasonography in pediatric blunt trauma patients: a meta-analysis. *J Pediatr Surg* 2007;42:1588-94.
80. Menichini G, Sessa B, Trinci M, Galluzzo M, Miele V. Accuracy of contrast-enhanced ultrasound (CEUS) in the identification and characterization of traumatic solid organ lesions in children: a retrospective comparison with baseline US and CE-MDCT. *Radiol Med* 2015;120:989-1001.
81. Anderst JD. Chylothorax and child abuse. *Pediatr Crit Care Med* 2007;8:394-6.
82. Bennett BL, Chua MS, Care M, Kachelmeyer A, Mahabee-Gittens M. Retrospective review to determine the utility of follow-up skeletal surveys in child abuse evaluations when the initial skeletal survey is normal. *BMC Res Notes* 2011;4:354.
83. Kleinman PK, Nimkin K, Spevak MR, et al. Follow-up skeletal surveys in suspected child abuse. *AJR Am J Roentgenol* 1996;167:893-6.
84. Harlan SR, Nixon GW, Campbell KA, Hansen K, Prince JS. Follow-up skeletal surveys for nonaccidental trauma: can a more limited survey be performed? *Pediatr Radiol* 2009;39:962-8.
85. Islam O, Soboleski D, Symons S, Davidson LK, Ashworth MA, Babyn P. Development and duration of radiographic signs of bone healing in children. *AJR Am J Roentgenol* 2000;175:75-8.
86. American College of Radiology. ACR Appropriateness Criteria® Radiation Dose Assessment Introduction. Available at: <http://www.acr.org/~/media/ACR/Documents/AppCriteria/RadiationDoseAssessmentIntro.pdf>. Accessed November 1, 2016.

Appendix 1. Complete skeletal survey table [16]

Appendicular Skeleton

- Humeri (AP)
- Forearms (AP)
- Hands (PA)
- Femurs (AP)
- Lower legs (AP)
- Feet (PA or AP)

Axial Skeleton

- Thorax (AP and lateral), to include ribs* and thoracic and upper lumbar spine
- Pelvis (AP), to include the mid lumbar spine
- Lumbosacral spine (lateral)
- Cervical spine (AP and lateral)
- Skull (frontal and lateral)

AP = anteroposterior; PA = posteroanterior.

*The addition of both oblique projections to the AP view of the rib cage may increase the yield of rib fractures.